

DESIGN OF A PIPELINE FOR THE DETECTION, TRACKING AND CLASSIFICATION OF ROAD SIGNS

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Design of a Pipeline for the Detection, Tracking and Classification of Road Signs

by

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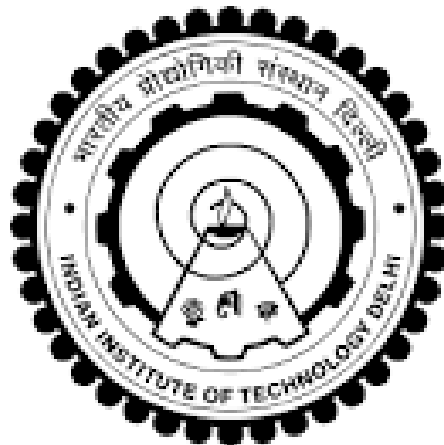
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Certificate

This is to certify that the thesis titled “Design of a Pipeline for the Detection, Tracking, and Classification of Road Signs” being submitted by Farah Jamal Ansari to the Department of Electrical Engineering, Indian Institute of Technology Delhi, for the award of the degree of Doctor of Philosophy, is a record of bonafide research work carried out by her under our guidance and supervision. In our opinion, the thesis has reached the standards, fulfilling the requirements of the regulations relating to the degree.

The results contained in this thesis have not been submitted to any other university or institute for the award of any degree or diploma.

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ABSTRACT

This thesis is concerned with the development of an Advanced Driver Assistance System (ADAS) that informs drivers about the safety instructions deciphered from the road signs on the signposts to prevent untoward incidents. To this end, two pipelines with the first comprising the road sign detection and classification modules (called DC-based) and the second comprising an additional tracking module (called DTC-based) are attempted in this thesis with a view to making them functionally effective and computationally inexpensive.

A Color-Based Detector (CBD) is chosen for the detection of road signs, which utilizes the information theoretic threshold condition for localization, the normalized RGB features, the histogram of gradients (HOG), and a Support Vector Machine (SVM) for the detection of road signs, and a two-stage multiscale Convolutional Neural Network (CNN) model for the classification. This CBD is shown to have the best recall and speed. A preliminary study has been conducted to address the hazardous conditions, such as rainy and poorly-lit world scenes, using the sigmoid-based enhancement operator.

To reduce the false positives, a Tracking Framework (TF) is developed based on the Intersection over Union (IoU) and the correlation coefficient (CC). This TF, assisted by CC, tracks the road signs across frames using a sliding window approach that aids in locating the road signs missed by the detector. Alternatively, two learning-based trackers named Particle competitive cooperative learning model (PCCLM) based tracker using the existing CCLM and Particle self-learning model (PSLM) based tracker using the new SLM are developed. For road sign tracking, both PCCLM and PSLM trackers were found to perform better than the well-known Kalman filter.

For the classification of the detected and tracked road signs, the above CNN model is utilized, and an experimental rejection threshold reduces the false positives. To take account of the uncertainty in the road signs, feature maps from appropriate layers of the deep learning neural network architectures are converted into the deep hesitancy features, classified by SVM. Three variants of the Hanman transform (HT) classifier, of which the fast and faster variants operate by delinking the training feature vectors from the test feature vectors, are also developed to deal with the uncertainty in the feature values and to reduce the computational complexity. In this, the HT called a criterion function works on the t-normed error vectors between the training feature vectors of each class and a test feature vector to identify the class label of the test sample. The proposed Detection Classification (DC) and Detection-Tracking-Classification (DTC) based two pipelines are compared on different datasets with the created pipelines using the literature tools and are shown to outperform them.

Some of the noteworthy contributions of the thesis include: i) formulation of new detectors based on the normalized RGB features and the HOG features, ii) development of the incremental hesitancy features using the pervasive membership function concept that accounts for the deficiency in the fuzzy modelling, iii) proposition of the correlation coefficient based TF, iv) development of two learning-based trackers, and v) the design of both the fast and faster Hanman transform classifiers aimed at speeding up the classification of the confirmed road signs.

सारांश (Abstract)

यह शोध-प्रबंध एक उन्नत चालक सहायता प्रणाली (Advanced Driver Assistance System—ADAS) के विकास से संबंधित है, जो वाहन चालक को साइनपोस्ट पर उपलब्ध सड़क संकेतों (road signs) से प्राप्त सुरक्षा निर्देशों की व्याख्या कर उन्हें सूचित करती है, ताकि अवांछित/दुर्घटनाजन्य घटनाओं को रोका जा सके। इस उद्देश्य हेतु, इस शोध-प्रबंध में दो पाइपलाइनों का प्रयास किया गया है—पहली में सड़क संकेत पहचान (detection) तथा वर्गीकरण (classification) मॉड्यूल सम्मिलित हैं (जिसे DC आधारित कहा गया है), जबकि दूसरी में एक अतिरिक्त ट्रैकिंग (tracking) मॉड्यूल भी सम्मिलित है (जिसे DTC आधारित कहा गया है)—ताकि ये दोनों कार्यात्मक रूप से प्रभावी तथा गणनात्मक रूप से कम खर्चीली बन सकें। सड़क संकेतों की पहचान के लिए कलर-बेस्ड डिटेक्टर (Color-Based Detector) (CBD) को चुना गया है, जो सूचना-सैद्धांतिक (information theoretic) थ्रेशहोल्ड कंडीशन के माध्यम से लोकेलाइजेशन करता है, तथा नॉर्मलाइज़्ड आरजीबी फीचर्स (normalized RGB features), हिस्टोग्राम ऑफ ग्रेडिएंट्स (Histogram of Gradients) (HOG) और सपोर्ट वेक्टर मशीन (Support Vector Machine) (SVM) का उपयोग करके सड़क संकेतों की पहचान करता है; साथ ही वर्गीकरण के लिए टू-स्टेज मल्टीस्केल कन्वोल्यूशनल न्यूरल नेटवर्क (two-stage multiscale Convolutional Neural Network) (CNN) मॉडल का प्रयोग किया गया है। यह CBD उच्चतम रि कॉल और तेज़ गति प्रदर्शित करता है। इसके अतिरिक्त, वर्षा तथा कम-रोशनी (poor-lit) जैसी हानिकारक परिस्थितियों को संबोधित करने हेतु सिग्माइड-आधारित एन्हांसमेंट ऑपरेटर (sigmoid-based enhancement operator) के उपयोग पर एक प्रारंभिक अध्ययन किया गया है। फॉल्स पॉज़िटिव्स (false positives) को कम करने के लिए इंटरसेक्शन ओवर यूनियन (Intersection over Union) (IoU) तथा कोरिलेशन कोएफिशिएंट (correlation coefficient) (CC) पर आधारित एक ट्रैकिंग फ्रेमवर्क (Tracking Framework) (TF) विकसित किया गया है। यह TF CC की सहायता से स्लाइडिंग विंडो अप्रोच (sliding window approach) का उपयोग करते हुए फ्रेमों के बीच सड़क संकेतों को ट्रैक करता है, जिससे डिटेक्टर द्वारा छूटे हुए सड़क संकेतों को भी लोकेट करने में सहायता मिलती है। वैकल्पिक रूप से, दो learning-based trackers—(i) पार्टिकल कम्पटीटिव कोऑपरेटिव लर्निंग मॉडल (Particle competitive cooperative learning model) (PCCLM) आधारित ट्रैकर (जो existing सीसीएलएम (CCLM) का उपयोग करता है) तथा (ii) पार्टिकल सेल्फ-लर्निंग मॉडल (Particle self-learning model) (PSLM) आधारित ट्रैकर (जो नए एसएलएम (SLM) का उपयोग करता है)—भी विकसित किए गए हैं। सड़क संकेत ट्रैकिंग के लिए, पीसीसीएलएम (PCCLM) और पीएसएलएम (PSLM) दोनों ट्रैकर्स का प्रदर्शन विख्यात कालमैन फ़िल्टर (Kalman filter) की तुलना में बेहतर पाया गया है। पहचाने गए तथा ट्रैक किए गए सड़क संकेतों के वर्गीकरण के लिए उपर्युक्त सीएनएन मॉडल (CNN model) का उपयोग किया गया है और एक प्रायोगिक रिजेक्शन थ्रेशहोल्ड (experimental rejection threshold) द्वारा फॉल्स पॉज़िटिव्स (false positives) को कम किया गया है। सड़क संकेतों में उपस्थित अनिश्चितता (uncertainty) को ध्यान में रखते हुए, डीप लर्निंग न्यूरल नेटवर्क आर्किटेक्चर्स की उपयुक्त लेयर्स से प्राप्त फीचर मैप्स (feature maps) को डीप हेज़िटेंसी फीचर्स (deep hesitancy features) में परिवर्तित किया गया है, जिनका वर्गीकरण एसवीएम (SVM) द्वारा किया जाता है। इसके अतिरिक्त, हनमन ट्रांसफॉर्म (Hanman transform) (HT) क्लासिफ़ायर (classifier) के तीन वैरिएंट विकसित किए गए हैं, जिनमें फास्ट (fast) तथा फास्टर (faster) वैरिएंट्स ट्रेनिंग फीचर वेक्टर्स (training feature vectors) को टेस्ट फीचर वेक्टर (test feature vector) से डीलिंग (delink) करके अनिश्चित फीचर वैल्यूज़ (feature values) को संभालने और संगणनात्मक जटिलता (computational complexity) घटाने में सहायक होते हैं। इसमें, क्राइटेरियन फंक्शन (criterion function) के रूप में एचटी (HT), प्रत्येक क्लास (class) के ट्रेनिंग फीचर वेक्टर्स (training

feature vectors) और टेस्ट फीचर वेक्टर (test feature vector) के बीच बने टी-नॉर्म्ड एरर वेक्टर्स (t-normed error vectors) पर कार्य करके टेस्ट सैंपल (test sample) का क्लास लेबल (class label) निर्धारित करता है। प्रस्तावित डिटेक्शन-क्लासिफिकेशन (Detection-Classification) (DC) तथा डिटेक्शन-ट्रैकिंग-क्लासिफिकेशन (Detection-Tracking-Classification) (DTC) आधारित दोनों पाइपलाइनों की तुलना विभिन्न डेटासेट्स (datasets) पर साहित्य (literature) में उपलब्ध टूल्स (tools) तथा निर्मित बेसलाइन पाइपलाइन्स (baseline pipelines) के साथ की गई है, और परिणामों से यह सिद्ध हुआ है कि प्रस्तावित पाइपलाइनें उनसे बेहतर प्रदर्शन करती हैं। इस शोध-प्रबंध के कुछ महत्वपूर्ण योगदान निम्नलिखित हैं: i) नॉर्मलाइज़्ड आरजीबी फीचर्स (normalized RGB features) तथा हॉग फीचर्स (HOG features) पर आधारित नए डिटेक्टर (detectors) का निर्माण, ii) परवेसिव मेम्बरशिप फंक्शन (pervasive membership function) की अवधारणा का उपयोग करते हुए इन्क्रिमेंटल हेज़िटेंसी फीचर्स (incremental hesitancy features) का विकास, जो फज़ी मॉडलिंग (fuzzy modelling) की कमी को संबोधित करता है, iii) कोरिलेशन कोएफिशिएंट (correlation coefficient) (CC) धारित टीएफ (TF) का प्रस्ताव, iv) दो लर्निंग-बेस्ड ट्रैकर्स (learning-based trackers) का विकास, तथा v) पुष्टि किए गए सड़क संकेतों के वर्गीकरण को तेज़ करने हेतु फास्ट (fast) तथा फास्टर (faster) हनमन ट्रांसफॉर्म क्लासिफायर्स (Hanman transform classifiers) का डिज़ाइन।

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List of Acronyms

DNN Deep Neural Network

ROIs Regions of Interest

YOLO You Only Look Once

SSD Single Shot Detector

FFP Fast Feature Pyramid

CCLM Competitive Cooperative Learning Model

PCCLM Particle Competitive Cooperative Learning Model

SVM Support Vector Machine

HOG Histogram of Oriented Gradients

SIFT Scale-Invariant Feature Transform

SURF Speeded-Up Robust Features

LBP Local Binary Pattern

CNN Convolutional Neural Network

BTSC Belgium Traffic Sign Classification

GTSRB German Traffic Sign Recognition Benchmark

GTSDB German Traffic Sign Detection Benchmark

DITS Dataset of Italian Road Signs

CURE-TSD Challenging Unreal and Real Environment for Traffic Sign Detection

R-CNN Region-based Convolutional Neural Network

IOU Intersection Over Union

TSDTC Traffic Sign Detection, Tracking, and Classification

KNN K-Nearest Neighbor Algorithm

LDA Linear Discriminant Analysis

HSV Hue, Saturation, Value

YCbCr Y (Luma), Cb (Blue minus Luma), and Cr (Red minus Luma)

CTSD Chinese Traffic Sign Dataset

CLAHE Contrast Limited Adaptive Histogram Equalization

ICF Integral Channel Features

ANN Artificial Neural Network

FFPs Fast Feature Pyramids

ACF Aggregate Channel Features

ADAS Advanced Driver Assistance System

RBF Radial Basis Function

NMS Non-Maximum Suppression

HT Hanman Transform

MHT Mamta-Hanman Transform

TF Tracking Framework

CBDN Color-based Detector using Normalized RGB Features

CBDG Baseline Color-based Detector using HOG Features

BCBD Baseline Color-based Detector using RGB and HOG Features

CBDH CBD using Hesitancy and HOG Features

CBDMH CBD using Mean Hesitancy and HOG Features

BCBD-YCNN BCBD + CNN using Y Features

CBDH-YCNN CBDH + CNN using Y Features

CBDMH-YCNN CBDMH + CNN using Y Features

YOLOv5-YCNN YOLOv5 + CNN using Y Features

VHTC Variant of Hanman Transform Classifier

F-VHTC Fast Variant of Hanman Transform Classifier

FR-VHTC Faster Variant of Hanman Transform Classifier

DC Detection-and-Classification

DTC Detection-Tracking-and-Classification

CCTF Correlation Coefficient-based Tracking Framework

PSLM Particle Self Learning Model